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AN OVERVIEW OF ENROUTE RADIO NAVIGATION SERVICES FOR CIVIL AVIA--ETC(U)
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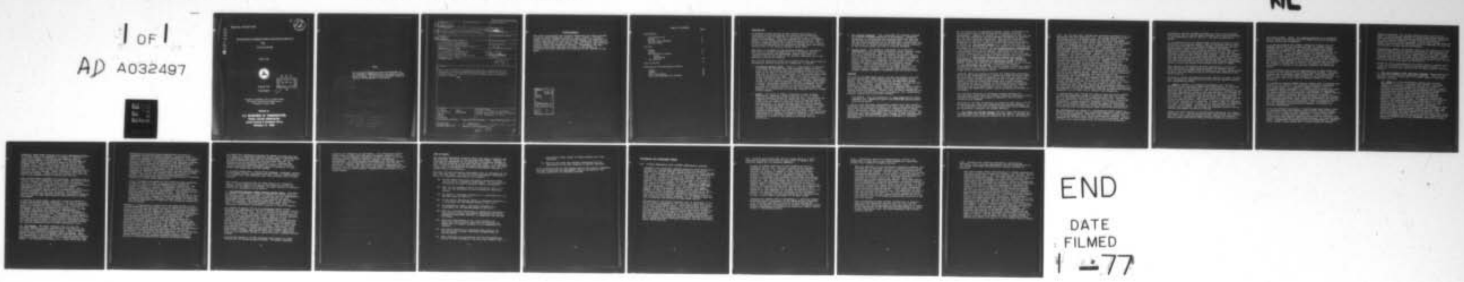

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AN OVERVIEW OF ENROUTE RADIO NAVIGATION SERVICES FOR CIVIL AVIATION

Carlo Yulo

August 1976

Final Report

Prepared for

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16. Abstract

This report presents (1) an overview of radio aids to navigation for civil aviation and (2) outlines engineering and development efforts that would be responsive both to the needs of the aviation community and to the budgetary concerns of Congress.

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INTRODUCTION

A confusing picture appears to have evolved with respect to alternative navigation systems for aviation and non-aviation applications, many of which are in use today or are in various stages of development. This has provoked the concern of Congress relative to the proliferation of radionavigation systems. The aviation community shares this concern, specifically as it relates to the implied possibility of phasing-out systems that have been an inherent part of the National Airspace System (NAS).

This paper (1) presents to the aviation community an overview of radio aids to enroute navigation for civil aviation, and (2) outlines engineering and development efforts that would be responsive both to the needs of the aviation community and to the budgetary concerns of Congress.

The aviation navigation needs can be sorted into four broad types of geographical service areas and are summarized as follows:

1. Continental United States - There is a requirement to modernize or replace the existing Very High Frequency Omnidirectional Range (VOR) and Distance Measuring Equipment (DME) facilities, based on the need to minimize system life-cycle costs and at the same time to fulfill U.S. commitments to the International Civil Aviation Organization (ICAO). Due to the limited (line-of-sight) coverage of both VOR and DME, it is also necessary either to add like facilities or to introduce a different, supplemental system, so as to achieve complete coverage in mountainous areas. A similar requirement (except for the ICAO commitment) applies to TACAN, the military Tactical Air Navigation system, which provides the distance function of the civil system (VOR-DME) wherever it is installed, and with VOR comprises the U.S. Common System (VORTAC).

2. Alaska - The State of Alaska, undergoing a major economic development, presents a posture akin to that of our North American continent during the early-1900 era. The vastness and ruggedness of Alaska, and the remoteness of many developing places from one another, impose an increasing demand for air transportation. It is the airplane that can best accommodate the topography and support the development of Alaska as a State in much the same way that the railroads made possible a rapid economic growth among the contiguous 48 states. Future air-navigation requirements can only increase with discovery of more opportunities to develop the Alaskan wilderness. The immediate requirement for expanding coverage of existing aids to navigation is based on oil-pipeline activities and oil exploration.

3. Low Altitude Offshore - The requirement for offshore coverage is to serve a growing population of helicopters. Operators supporting oil exploration and production make many runs each day between drill platforms and landside bases. In addition, air-sea rescue operations can be increasingly effective with the availability of reliable navigation aids which permit reduction of the on-board weight and bulk of existing equipment.

4. Oceanic Areas - The immediate requirement to arrange for replacement of the Long Range Navigation System, LORAN-A, stems from its obsolescence. However, because of its inherent relatively-limited coverage, the LORAN-A transmitter complex, even if rehabilitated, could not grow sufficiently to support global navigation. A replacement system is also needed to fulfill the function of updating, or correcting in flight, the Doppler Navigation System of many trans-oceanic carrier aircraft. Future world commerce will expand its flight operations into the South Atlantic and South Pacific. With suitable oceanic coverage, air carriers hope eventually to achieve complete freedom of navigation over the entire world.

OVERVIEW

The existing VOR-DME-VORTAC system can meet the present civil and military operational requirements within the contiguous United States. So, of course, can a modernized VOR-DME-VORTAC system. However, other available or proposed systems might be used for this purpose as alternatives. Among these are LORAN-C, Omega, Differential Omega, VLF NAVCOM*, Satellites (NAVSTAR GPS**, Transit, etc.) and self-contained systems (inertial navigation system and Doppler Navigation System.) Further, many of these alternatives can also meet the expanded operational requirements, viz., mountainous, oceanic, Alaska, and low altitude offshore.

*VLF NAVCOM - Very Low Frequency U.S. Navy Communication System
**NAVSTAR GPS - Navigation System Using Time and Ranging Global Positioning System

It may be noted that many knowledgeable experts feel that avionics technology will eventually produce a low-cost, self-contained system which will revolutionize air navigation, perhaps based on atomic clocks, satellites, recent developments in digital mini- and micro-computers, and future development of low-cost inertial devices. The FAA Engineering and Development effort speaks to this consideration. Meanwhile, this overview of necessity is addressed to available alternatives.

One or more of the air navigation systems, either independently or in some combination, might be expected to satisfy the broad requirements. However, it remains to be determined how each one can fit into the operational and environmental parameters of aviation. What are their specific limitations? What are the advantages available for trade-offs? What will implementation cost on the ground and in the air? Study and analysis are needed specifically to assess: (1) the economic impact, i.e., capital that must be allocated for avionics by the user, the capital to be allocated for the system by the Government; (2) the political/social consequences - the international and the domestic considerations, the threat of a proliferation of navigation systems, preferences of the civil aviation community for a given navigation system, and the Military presence in a common environment of ATC/Navigation with non-military operators; (3) how systems' capabilities compare with present requirements, individually and collectively; (4) the ability of systems to meet the technical and operational needs, not only of present service, but also of the less-easily-defined future service; (5) the requirement for capital to overcome any technical limitations of each system. The capital needed to carry out further investigations would include studies, laboratory tests, simulation, flight tests, and operational tests.

Prominent among the principal criteria for comparative evaluation should be the compatibility of a system with area navigation (RNAV). The introduction of RNAV is expected to save time, air space and operating cost, thereby benefiting both the air space user and ATC system. Simulation studies have shown that a mixed VOR/RNAV environment may not be expected to add appreciably to controller workload or to adversely affect the air traffic system. RNAV is currently used on a limited basis in U.S. aviation, and it is stipulated that RNAV will become a major navigational procedure in the 1980's.

The following discussion of prominent systems available for selection will assume that all residual technical limitations can be removed from each in any program to develop it into a viable navigation aid (NAVAID).

Estimates of the cost of avionics, as quoted in this report, are to be used only for first order comparison and overview purposes. It is not intended to reflect the actual market cost since technology and production techniques are rapidly changing.

1. The VORTAC and VOR-DME Systems. The well known VOR has been in existence since the 1940's and DME since the 1950's. Together they have provided good navigation signals at low cost to the aviation

user. For the most part, VOR-DME has satisfied requirements for air navigation over the continental U.S. The airway structure of the ATC system, which is designed around the VOR-DME system, meets today's demand for air routes within the contiguous continental U.S. To provide coverage of these routes, there are over 1000 FAA ground stations throughout the U.S. with a capital investment of over $250M. It is estimated that users (civil and military) have invested some $800M in VORTAC avionics. Furthermore, the system has been accepted internationally. By agreement reached within ICAO, the FAA must operate its VOR-DME's through 1985 without revising standards of the present system. (TACAN is not involved in the ICAO agreement). The fact that many foreign countries have recently installed modern ground and airborne VOR-DME equipments reinforces the probability that several nations will request extension of the present ICAO agreement to at least 1995. Meanwhile, the U.S. Military will not have a partly operational (two-dimensional capability) navigation system based on satellites before 1980-81, and a fully operational (three and four-dimensional) system before 1984; therefore it will continue to depend on the TACAN portion of the VORTAC for services at least until the 1990's when transition is planned to the NAVSTAR system. VORTAC provides azimuth information, both at VHF and UHF frequencies and also distance at UHF frequencies, while VOR-DME does not provide azimuth information at UHF frequencies. Even if the agreement with ICAO for VOR-DME services should expire in 1985, and the FAA should select a new system, the FAA will need to continue to operate VORTAC until 1995 or possibly until 2000. FAA will be obliged to protect the purchasers of civil aircraft containing the navigation package, or who will have VOR and DME equipment installed in their airplanes and helicopters in the early 1980's time frame by providing the aviation community 10 to 15 year life to amortize such equipments.

It appears then, that the FAA will have to keep the current VORTAC and VOR-DME navigation system in operation until the year 2000, while a replacement cannot be introduced before 1985. Therefore, the vast majority of all existing ground stations will require the replacement of major electronic equipments and components which cannot be maintained without a continuing supply of obsolescent spare parts, such as tubes and relays; obsolescence contributed to the high operation and maintenance (O&M) cost of $38 million/year.

The implementation in Alaska of a comprehensive VORTAC system (or TACAN by itself), has not been found cost-beneficial largely because of the sparse population, relatively light traffic density over a very wide geographical area, severe environmental problems, limited accessibility of sites which would have to be established, and from all this a very high probable cost of operation and maintenance.

Furthermore, because VOR-DME and TACAN are line-of-sight systems, restrictions due to limited signal coverage, as we are experiencing in the mountainous areas of the U.S., can also be expected in Alaska.

It is noteworthy that the TACAN azimuth information would be less susceptible to multipath effects, cost of its ground station would be less than the cost of a complete VORTAC installation, and the TACAN avionics could be used also in a VORTAC environment. Nevertheless, today's civil aircraft generally do not carry TACAN. Addition of TACAN avionics would burden civil aviators with an additional cost of over $10K for each aircraft. This cost probably could be reduced to $3K at high sales volumes. Those who already have DME could add the azimuth information provided by TACAN for $5K and could hope eventually to buy avionics for $1K. Air navigation services for the oceanic area and low-altitude offshore requirements cannot be satisfied beyond line-of-sight with TACAN or VORTAC.

When applied to low-altitude offshore applications, the line-of-sight limitation of TACAN could influence the minimum enroute altitude, and the minimum decision heights at oil rigs, particularly if there were more than one rig in the area being serviced by one TACAN facility.

In order to convert the existing VOR-DME avionics for RNAV, off-the-shelf equipment is available which would cost the general aviation user approximately $2000.

2. <u>LORAN-C.</u> LORAN-C is a pulsed low-frequency (LF), 100 kHz, hyperbolic radio navigation system with baselines up to 500 miles; may be usable to over 1000 miles. The system operates on the principle that the difference in time of arrival of signals from two stations, observed at a point in the coverage area, is a measure of the difference in distance from the point of observation to each of the stations. The focus of all points having the same observed difference in distance to a pair of stations is a hyperbola, called a line of position (LOP). The intersection of two or more LOP's defines the position of the observer. A LORAN-C chain is comprised of a master transmitting station, two or more secondary transmitting stations. The transmitting stations are located such that the signals from the master and at least two secondary stations can be received throughout the desired coverage.

LORAN-C has been selected as the Navigation System for the coastal confluence zone. The United States Coast Guard (USCG), has advised that only five additional LORAN-C ground stations are needed to achieve ground coverage for coast-to-coast navigation over the 48 contiguous states. (Note: For aviation purposes it is projected that at least twice as many would be needed to provide acceptable standby service and redundancy.)

It is now anticipated that LORAN-C Navigation Services will be expanded within the next few years so that (1) LORAN-C signal coverage will be available; (2) suitable avionics will become commercially available; (3) LORAN-C will be found technically acceptable; and (4) to some elements of civil aviation it will be cost-beneficial. These prospects suggest a prominent role for LORAN-C in civil aviation. In particular, it can supplement the coverage of VOR-DME in geographic areas (offshore and mountainous areas) not served adequately by the VOR-DME, it can exist compatibly and operate independently in parallel with VOR-DME over the entire ATC airspace; in post-1985 it will be a promising candidate for replacement of VOR-DME as the principal domestic air navigation system.

It is noteworthy that avionics requirements of an RNAV system are inherent in the avionics of an airborne LORAN-C system. Currently, avionics for an automatic LORAN-C Navigator cost approximately $25K; in the near future cost probably can be reduced to $10K. In the far future the price could be reduced to $2000, if widely installed.

As a potential domestic NAVAID system, LORAN-C must be examined with respect to its potential for conducting nonprecision approaches. This investigation is to ascertain whether LORAN-C can be a replacement and/or supplement for VORTAC and to determine what must be added or changed to make it such a replacement or supplement. The safety aspects of the transition from VOR-DME to LORAN-C must be carefully inspected because, during this period, aircraft in adjacent airspace could well be using different navigation systems. Certification procedures, pilot training requirements, and possible ATC accommodations to the dual system during the transition period all need thorough study and resolution. This investigation is equally necessary for application of LORAN-C to offshore low-altitude requirements.

As for the Alaskan requirement, it would appear that LORAN-C could be applicable along the southern areas and the Aleutian Islands. Service will be improved upon completion of the proposed LORAN-C chain for the Alaskan coastal confluence. However, there are reservations about whether adequate coverage can be provided along inland valleys shielded by high mountain ranges, and along the North Slope. Furthermore, difficulties have been encountered at LORAN-A and at LORAN-C installations due to severe storms and extreme weather conditions. One serious question arises regarding the impact on usable-signal coverage of ground-conductivity variations, which presently disturb Alaskan non-directional beacons (NDB's) in the same frequency spectrum. Severe adverse environmental conditions and the rugged topography in areas where ground sites are needed could not only put practical limits on coverage, but also the reliability of ground station maintenance.

Nevertheless, LORAN-C can provide service at the surface and at low altitude offshore and the accuracy (estimated at approximately 1/4 mile) and RNAV potential make it attractive for such applications. The projected coverage area also makes LORAN-C attractive. However, although existing chains already supply the basic NAVAID signals, airborne avionics have not yet been installed by many users, nor has the system found favor among air navigators.

Because of siting requirements for stations within a LORAN-C chain, it may not be possible to obtain complete global coverage or to expand its coverage into open areas of the South Atlantic and South Pacific.

3. Very Low Frequency (VLF) Navigation Systems. These systems use the hyperbolic technique as previously discussed. There are two different methods of using VLF (3 to 30kHz) signals in the same frequency spectrum.

(a) Omega is a very-low-frequency system based on phase comparison; it too is a "natural" RNAV system. Each Omega station, in sequence, broadcasts the same set of three frequencies on a time-shared, non-interfering basis. Signals received are affected by the well-documented VLF propagation characteristics within the spherical waveguide between ionosphere and earth. Eight transmitting stations are sufficient to provide world-wide coverage for maritime navigation. System accuracy is expected to be within two nautical miles 95% of the time. An important consideration in Omega is the existence of position ambiguities, i.e., the necessity for resolving which "lane" the user is in after a system outage. At the 10.2 kHz principal frequency, a particular phase difference is repeated, and an ambiguity thus created, every 8 nautical miles; this becomes the basic lane width when the single-frequency receiver is used. When more costly receivers are used, capable of accepting the two additional Omega radiations at 11.33 and 13.6 kHz, a lane width of 72 is produced, with a corresponding 9-to-1 reduction in the number of ambiguities and the consequent difficulty of their resolution.

Presently, seven Omega stations are at full operational status. The eighth station is proposed to be located in Australia; a treaty with respect to installing and operating such an installation remains to be negotiated. (In the meantime, an Omega transmitter in Trinidad will remain on the air until December 1976. Indications are that this period will be extended through 1977.) With eight stations (which include Australia and exclude Trinidad) five station signals at any point on earth. Three signals are required for navigation with the early avionics designs. (With a precision clock only two signals are needed). Operation of each station will be by the host nation through bilateral treaties with the U.S.

Some airborne Omega equipments are available. Estimated cost of airborne units for commercial carriers ranges from $12K to $35K. Low cost systems below $6K for light aircraft are becoming available. The USAF is currently developing relatively low-cost (approximately $10K) systems to be used as a LORAN-A replacement, and plan to buy as many as 1000 units. This military procurement should result in considerably more activity in the development of low cost receivers. The commercial carriers through their Airlines Electronic Engineering Committee plan to adapt the USAF specifications when procuring a LORAN-A replacement.

In addition to Omega being a potential navigation system for oceanic application (global coverage), it can also be operated in the low altitude-offshore application. By using Differential Omega it is expected to assure accuracy within 1/4 mile; if successful, it can be considered as an approach aid. It does not appear that Omega will satisfy all requirements of a navigation system over the continental U.S. but Differential Omega may be able to do the job. Consequently, it too may be a potential VOR-DME supplement. (The Differential Omega technique transmits local error-connection information derived at the local ground station where an Omega monitor continuously samples the received Omega signals and measures the difference between the received information and its known geographical fix.)

(b) VLF NAVCOM. The other technique uses the very low frequency signals currently transmitted at high power by the U.S. Navy for communication with its fleet. Each transmitter broadcasts on a different assigned carrier frequency. This system, referred to as "VLF NAVCOM" (NAV here denotes "Navy", not "navigation.") could be developed to provide global coverage usable for enroute applications. It is another "natural" RNAV system. Its accuracy is estimated at $\pm$ 1 mile 95% of the time.

Ambiguities are possible since computations are based on comparison of pairs of received signals. Accuracy could be improved to within 0.25 miles through techniques in which error-correction information is broadcast from the ground to traffic within a local area. Two manufacturers have developed airborne equipment that navigates by operating on VLF NAVCOM signals. The present oil drilling activities offshore have led to installation of the readily available VLF NAVCOM airborne receivers in numerous helicopters. There are approximately 1000 receivers in operation both in business aircraft and helicopter communities. Cost of the airborne units have ranged from $15K to $45K. Newer units are including Omega capabilities. Manufacturers stated they would provide modification to existing avionics to include Omega capabilities.

A major limitation on growth of this method has been reluctance of the U.S. Navy to accept responsibility for adding the navigation mission to its VLF communications operations. The FAA has attempted to establish an agreement with the Navy to modify its procedures so it can accommodate air navigation with reliable and continuous VLF transmission. Such efforts have not been successful and the prognosis is poor. Operational communications must retain priority and the Navy may not be able to disseminate early warning of station shutdowns necessary for emergency maintenance. Therefore, further efforts to refine the VLF NAVCOM avionics for a stand-alone VLF navigation system have been minimized.

Meanwhile, a combination of signals from the Omega system and from the USN communications VLF network has been exploited. Both types of signal are in the same VLF band, and much of the existing VLF NAVCOM avionics equipment can be adapted for combined Omega/VLF operation after which users may have immediate service not presently available in many remote and offshore sites. This technique would require some additional equipment at the Omega ground stations. VLF transmissions would be broadcast from each Omega station on a discrete frequency, similar to the unique constant frequency now radiated by the VLF NAVCOM stations. The added VLF transmissions would last during those five of the eight Omega time slots when the particular station does not transmit Omega signals. The cost to accomplish this change should be minimal. With such an adaptation, the Omega/VLF NAVCOM concept has the potential of satisfying requirements of a continental VOR-DME supplement and of a system for the low-altitude offshore, ocean and Alaska areas; it would not change substantially the airborne navigation process by which position is being determined with existing VLF NAVCOM equipment.

The significant differences between VLF NAVCOM and Omega are that only Omega is a dedicated navigation system, and its radiated power is significantly less than that of the VLF NAVCOM. Due to the multiple frequencies radiating from each Omega station, the feasibility of re-initiating the flight (i.e., resetting the receiver following equipment outage to indicate the aircraft's current position within acceptable limits of accuracy), is much greater with Omega than with VLF NAVCOM.

It is worth noting that, the discrete frequency technique applied to each Omega station, individual stations could be identified with less complex and less expensive logic than presently used in Omega avionics.

Some commercial carriers must fly both oceanic and continental routes. Avionics may have to be provided which can respond to combinations of LORAN-C, VLF NAVCOM and Omega signals, if different systems are implemented on the ground.

4. The Proposed Military Global Position System (GPS), also known as NAVSTAR, is designed to fulfill a variety of critical military positioning needs. With the GPS, all-weather position determination may be expected at considerably improved accuracy and with performance characteristics better than those of the existing navigation systems. The complete operational target date is late 1984. It eventually would be capable of real-time, three-dimensional positioning information accurate to within 10 meters.

As a matter of policy, DOD is not encouraging others to make decisions or commitments on the use of NAVSTAR until Phase I testing has been completed in 1978. Phase I involves the deployment of six satellites in 12-hour inclined, circular orbits providing coverage of a test area for several hours a day. Phase II will be initiated in the early "eighties" with the planned orbiting of nine satellites, providing a full time, two-dimensional global coverage system. By the end of Phase II, a world-wide, 24-hour capability for navigation would exist with an initial accuracy of better than 600 feet and velocity accuracies of 2 knots. Phase III will add nine satellites in 1984 permitting continuous, world-wide, three-dimensional coverage. Current estimates for avionics range from $15K to $26K although some sources feel that a $2500 model would eventually be available making it competitive with a present VOR-DME package.

A world-wide system in the GPS frequency band could be an ideal solution for our future navigation needs. Its global coverage, accuracy and redundancy are impressive. Its configuration would allow a user to equip only the level necessary, starting from a simple 2-D single-channel arrangement to multi-channel 3-D or 4-D configuration for domestic enroute, terminal and approach applications. It would satisfy the offshore low altitude need and provide the accuracy required for oil exploration and drilling operations. However, the time frame for initial operational use does not meet the Alaskan near-term requirement. Nevertheless, this promising concept offers another candidate for replacement of the VORTAC system.

PLAN OF ACTION

The preceding discussion primarily dealt with types of hardware and the solutions they offer in the near-term time frame. However, to eliminate the appearance of proliferation of navigation systems we must address ourselves to the post-1985 time frame. It is necessary first to define and determine the applicable scenario for this time frame; then, to establish the navigation performance required to operate within this scenario.

The civil aviation navigation requirements will be validated for the post 1985 time frame. For each of those requirements confirmed as valid, the following questions will be answered:

(a) To what degree does each alternative navigation system satisfy the air navigation requirements; can any projected limitation be solved technically and/or procedurally?

(b) What are the probable capital and operating costs to the user and the government of each alternative navigation system?

(c) Is LORAN-C a reasonable candidate as a replacement for the VOR-DME system in the U.S.?

(d) Is the Global Positioning System a reasonable candidate as a replacement for the VOR-DME system in the U.S.?

(e) Is Differential Omega a reasonable candidate as a replacement for the VOR-DME system in the U.S.?

(f) What is a realistic definition of operational reliability and accuracy of Omega and LORAN-C considering the known anomalous propagation effects, in comparison with VOR-DME and TACAN.

(g) Could the requirements of U.S. civil aviation for navigation aids be better served by restructuring the Omega, GPS, or LORAN-C systems, or by a combination of systems?

(h) How should system errors associated with each of the various system concepts (including VOR-DME-TACAN) be characterized?

(i) What guidelines are appropriate for the error-budgeting aspect of route planning in the event that LORAN-C, GPS, or

Differential Omega should be found suitable for civil aviation?

(j) What are the costs and benefits associated with the application of low cost avionics to general aviation?

To be responsive both to the Congress and to the aviation community, the four engineering and development efforts presented in the following pages will be vigorously pursued.

ENGINEERING AND DEVELOPMENT EFFORT

One: Proceed immediately with a VORTAC modernization program.

VOR-DME is the universally adopted system for short-distance air navigation; through ICAO the United States has agreed to maintain and provide VOR-DME navigation service at least through 1985. The aeronautical users have a major capital investment in this system. Transitioning to a new technique, even if it is technically feasible and immediately available, would take a considerable period of time from both economic and logistics aspects. For these reasons, the VOR-DME must be available to some degree for approximately 20 years. Failure to modernize this system so as to maintain its reliability would not only increase Government and user costs but would also reduce safety. Recent cost-benefit studies indicate that over this period (20 years) it would be economical to modernize the system by replacing the obsolescent equipments installed almost 30 years ago with more efficient solid-state equipments requiring less energy and maintenance manpower. It is incumbent upon the FAA to modernize the existing VOR-DME-VORTAC system.

Introduction of solid-state equipment will be applicable to VOR-DME and VORTAC equipments at the locations at which firm civil or military requirements exist. Civil requirements for VOR-DME can be determined by re-examining the need for each existing airway and facility, by considering the application of RNAV, by introducing improvements such as Doppler VOR, and by adjusting the total quantity of equipment to be purchased accordingly. Military TACAN requirements can be re-examined directly with the DOD, by applying any proposed elimination of VOR-DME facilities, while considering FAA's continuing agreement with DOD to provide needed TACAN services.

Two: Actively participate with the U.S. Coast Guard in a joint coordinated program to clarify the application of LORAN-C as a potential NAVAID for the aviation community.

A chain of LORAN-C stations has been proposed by DOT for implementation by 1980. This will provide signal coverage throughout the U.S. As a result, other civil Government agencies are looking to LORAN-C as their navigation and/or position determination system for applications other than aviation. The Coast Guard is committed to LORAN-C for the coastal and confluence and waterways and maritime application, as well as their own requirement for air-sea rescue and flight operations. The signal coverage that will result from the planned coastal confluence installation and the accuracy of LORAN-C makes it a promising system to satisfy the offshore low altitude requirements and may have applications for nonprecision approaches. This special class of user may determine this system to be cost-effective to its mode of operation and will be pressing for certification for operation in the contiguous states. In addition, the FAA is considering the implementation of RNAV in post 1980's, and LORAN-C is an RNAV system.

Consequently, LORAN-C must be considered as a potential adjunct supplement and/or replacement of the VORTAC system. Therefore, it is incumbent upon FAA to determine if both VOR-DME and LORAN-C can operate in parallel as an aviation navigation system without compromising the existing and future air traffic control system or compromising safety.

Three: Concentrate efforts on investigations, studies, and comparisons to show what is the "best" system for a post-1985 primary civil aviation navigation system.

When one considers all the alternative navigation systems, many of which are in use today, one sees a confusing picture which has provoked the Congress' concern about the proliferation of radionavigation systems. The FAA needs to validate the current navigation requirements; it must project these requirements into the post-1985 period if it is to determine whether they will continue to be valid; and if not, FAA must state the requirements we may realistically expect. Valid requirements must be addressed to existing alternative navigation systems so as to determine the extent to which they can succeed. It may be necessary to develop a system design around the "best" or most promising system; that system would become "the" recommended civil aviation navigation system. A cost comparison of each alternative would disclose the most cost-beneficial approach to both the user and the operator. Any civil navigation system that evolves must also be a common system whereby the military can operate in the civil/common ATC/Navigation scenario of the post-1985 period.

FAA's investigations must include consideration of possible self-contained navigation systems which at this time are undefined, but which may emerge in the near future as a result of the application of new and predicted developments in atomic clocks, satellites, mini- and micro-computers, and low-cost inertial devices.

Four: Determine the technical performance, certification procedures, pilot training requirements and ATC accommodations of the various non-VORTAC radionavigation systems currently in operation.

The line-of-sight signal characteristics of VORTAC preclude its providing navigation services in offshore, low altitude, oceanic and mountainous areas. For these applications, FAA has not adopted a preferred system. In recent years, special classes of users have generated demands for such services in order to pursue their own livelihood or missions. Industry, recognizing this demand, has developed and produced avionics which meets the users' requirements. Once this equipment is purchased and installed on their airplanes or helicopters, users seek FAA approval for its use in operation in the VORTAC environment. The oil exploration and producing industry in 1974 conducted approximately one million helicopter operations in the Gulf of Mexico using VLF NAVCOM avionics. The Coast Guard uses LORAN-C for air-sea rescue and flight operations. Rocky Mountain Airways and Aspen Airways are continuously searching for an aid which will allow them to navigate safely in valleys and they are considering VLF NAVCOM. DOD has initiated a program for procurement of some 1000 Omega avionics units as a replacement for LORAN-A. The U.S. carriers and some European airlines are also leaning towards Omega as a LORAN-A replacement. It is incumbent upon the FAA to investigate the techniques and technical performance of VLF NAVCOM, Omega, LORAN-C and any other systems that may be developed and produced before FAA adopts a system. The FAA must determine if these systems can operate in parallel with VORTAC or among themselves without compromising safety of flight or the air traffic control system.